14.0 : Introduction

Q.1. What is magnetic effect of electric current? State the magnitude of force acting on a conductor of length 'l' carrying current 'I' and kept in a uniform magnetic field of induction 'B'.

Ans: i. The effect in which an electric current flowing through a conductor produces magnetic field around it is called as magnetic effect of an electric current.

ii. A conductor of length 'l' carrying current 'I', kept in a uniform magnetic field of induction' '$\vec{B}$' is acted upon by a force which is given by,

$\vec{F} = \vec{I}l \times \vec{B}$

Magnitude of tbis force is given by,

$F = |\vec{F}| \backslash I/B \sin\theta$

where, θ = angle between length of conductor and direction of magnetic induction.

iii. If the conductor carrying current is kept at right angles to the direction of magnetic field, then it is acted upon by a force which is given by,

$F = 1/B \sin 90° = I/B$

14.1 : Ampere's law and its applications

Q.2. State and explain Ampere's circuital law. **[Mar 12]**

Ans: Statement:

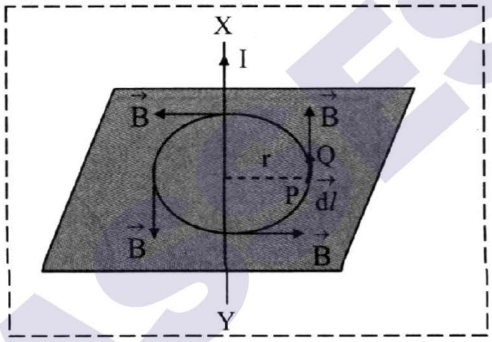
The line integral of magnetic field of induction $\vec{B}$ around any closed path in free space is equal to absolute permeability of free space μ_0 times the total current flowing through area bounded by the path.

Mathematically, $\oint \vec{B}.\vec{dl} = \mu_0 I$

Explanation:

i. Ampere's law is generalisation of Biot-Savart's law and is used to determine magnetic field at any point due to distribution of current.

ii. Consider a long straight current-carrying conductor XY, placed in vacuum. A steady current 'I' flows through it from the end Y to X as shown in the figure.



iii. Imagine a closed curve (amperian loop) around the conductor having radius 'r'.

iv. The loop is assumed to be made of large number of small elements, each of length $\vec{dl}$.

v. Its direction is along the direction of traced loop.

vi. Let $\vec{B}$ be the strength of magnetic field around the conductor.

vii. All the scalar products of $\vec{B}$ and $\vec{dl}$ give the product of μ_0 and I.

It is given by $\oint \vec{B}.\vec{dl} = \oint Bdl\cos\theta$

where, θ = angle between $\vec{B}$ and $\vec{dl}$

Q.3. Derive an expression for magnetic induction at a point near infinitely long straight conductor carrying an electric current on the basis of Ampere's law.

OR

State Ampere's law. Derive an expression for the magnetic induction at a point due to a long straight current-carrying conductor. **[Mar 09]**

Ans: Ampere's law:

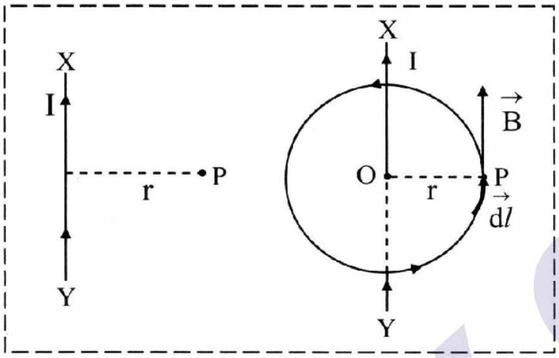
The line integral of magnetic field of induction $\vec{B}$ around any closed path in free space is equal to absolute permeability of free space μ_0 times the total current flowing through area bounded by the path.

Mathematically, $\oint \vec{B}.\vec{dl} = \mu_0 I$

Expression for the magnetic induction at a point due to a long straight current carrying conductor:

i. Consider a long straight conductor carrying a current 'I'. A point P is at a distance 'r' from the conductor. We have to find the magnetic induction at P due to this current carrying conduc

ii. Consider a circular Amperian loop of radius 'r', drawn in a plane perpendicular to the straight conductor, with the conductor passing through the centre of the circle. The direction of current is outwards at right angles to the plane of the circle.



iii. At every point of the loop, the magnetic induction $\vec{B}$ is directed in the tangential path. Therefore the angle between $\vec{B}$ and the current element $\vec{dl}$ is zero at all the points, i.e., $\theta = 0°$.

iv. Hence, the line integral along the closed loop is given by,

$$\oint \vec{B}.\vec{dl} = \oint B dl \cos\theta$$

$$\oint \vec{B}.\vec{dl} = \oint B dl \qquad [\because \cos 0° = 1]$$

$$\oint \vec{B}.\vec{dl} = \oint B dl = B\oint dl \qquad [\because B = \text{constant}]$$

$\therefore$ But, $\oint dl = 2\pi r$

$$\therefore \oint \vec{B}.\vec{dl} = B(2\pi r) \qquad \text{.... (i)}$$

v. According to Ampere's law,

$$\oint \vec{B}.\vec{dl} = \mu_0 I \qquad \text{.... (ii)}$$

vi. Comparing equations (i) and (ii), we get,

$$B(2\pi r) = \mu_0 I$$

$$\therefore B = \frac{\mu_0 I}{2\pi r} \qquad \therefore B = \frac{\mu_0}{4\pi}\frac{2I}{r}$$

This is the required expression.

Note:

$\frac{\mu_0}{4\pi}$ is a constant quantity which is equal to 10^{-7} Wb A^{-1} m^{-1}.

Q.4. Using Ampere's law, obtain an expression for magnetic induction due to the axis of a long straight solenoid.

Ans: Expression for magnetic induction due to the axis of a long solenoid:

i. A solenoid is a long, insulated copper wire closely wound on a hollow cylindrical glass or plastic tube in the form of a helix. Length of the solenoid is very large as compared to its diameter.

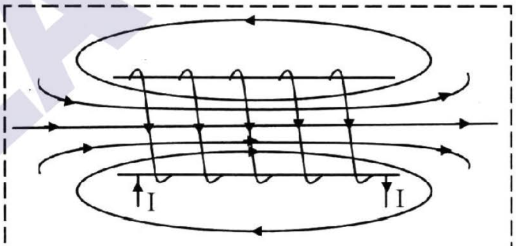


Figure (a)

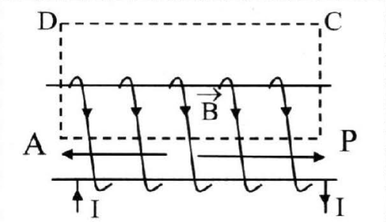


Figure (b)

ii. Consider a solenoid having n turns per unit length carrying a current of magnitude 'I'. Magnetic field is produced in the coil as shown in figure (a).
We have to find magnetic induction B due to solenoid.

iii. Consider APCD, a rectangular Amperian loop with AP = l, as shown in figure (b).

iv. Number of turns over the length 'l' of the solenoid = nl. Thus, current threading the loop = n/I.

v. Applying Ampere's law in loop APCD, we have,

$$\oint_{APCD} \vec{B}.\vec{dl} = \mu_0 \ (nl\ I) \qquad .... (i)$$

Also, $\oint_{APCD} \vec{B}.\vec{dl}$

$$= \oint_A^P \vec{B}\ .\ \vec{dl} + \oint_P^C \vec{B}\ .\ \vec{dl} + \oint_C^D \vec{B}\ .\ \vec{dl}$$

$$+ \oint_D^A \vec{B}\ .\ \vec{dl} \quad .... (ii)$$

vi. The direction of magnetic induction $\vec{B}$ is perpendicular to the path PC, DA.

$\therefore \quad \theta = 90°$

$$\therefore \quad \oint_P^C \vec{B}\ .\ \vec{dl} = \oint_D^A \vec{B}\ .\ \vec{dl} = \oint \vec{B}\ .\ \vec{dl} \cos 90° = 0$$

vii. Inside the solenoid, magnetic field is uniform. Magnetic field at the ends of a long solenoid is very much weak as compared to that of inside field. Hence in an ideal case, the magnetic field outside the solenoid is considered to be zero.

$$\therefore \quad \oint_C^D \vec{B}\ .\ \vec{dl} = 0$$

viii. Now using equation (ii), we get

$$\oint_{APCD} \vec{B}.\vec{dl} = \oint_A^P \vec{B}\ .\ \vec{dl} + 0 + 0 + 0$$

$$\therefore \quad \oint_{APCD} \vec{B}.\vec{dl} = \oint_A^P \vec{B}\ .\ \vec{dl}$$

ix. Along the path AP, $\vec{B}$ and $\vec{dl}$ are in same direction

$\therefore \quad \theta = 0°$

$$\oint_{APCD} \vec{B}.\vec{dl} = \oint_A^P \vec{B}\ \vec{dl} \cos\theta$$

$$= \oint_A^P \vec{B}\ \vec{dl} \qquad [\because \cos 0° = 1]$$

$$\therefore \quad \oint_{APCD} \vec{B}.\vec{dl} = \int_A^P dl$$

But, $\int dl = l$

$$\therefore \quad \oint_{APCD} \vec{B}.\vec{dl} = Bl \qquad .... (iii)$$

x. Comparing equations (i) and (iii), we have,

$Bl = \mu_0\ nIl$

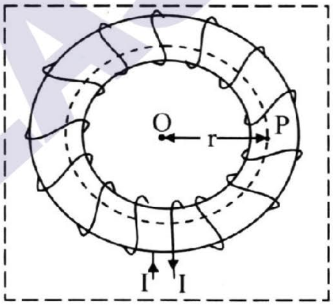
$\therefore \quad B = \mu_0\ nI$

This is required expression for magnetic induction of solenoid along its axis at a point well inside the solenoid.

Q.5. Using Ampere's law, derive an expression for magnetic induction at a point along the axis of a toroid.

Ans: Expression for magnetic induction at a point along the axis of a toroid:

i. A toroid is a long solenoid bent in the shape of a ring.



ii. The magnetic field around the toroid consists of concentric circular lines of force around it. Magnetic field is produced, when a steady current 'I' flows through toroid.

iii. The direction of magnetic field at a point is along the tangent to the circular path at that point.

iv. Let r be the radius of the Amperian loop. This loop is concentric with the axis of toroid. P is a point on the loop. We have to determine magnetic induction at P.

v. Applying Ampere's law, we have,

$$\oint \vec{B}.\vec{dl} = \mu_0 I\ NI \qquad .... (i)$$

where, N = total number of turns in the toroid.

NI = total current flowing through toroid.

Now, $\oint \vec{B}.\vec{dl} = \oint B\ dl\ \cos\theta$ .... (ii)

vi. But, $\vec{B}$ and $\vec{dl}$ are in same direction

$\therefore \quad \theta = 0°$

$\therefore \quad \cos\theta = 1$

∴ Equation (ii) can be written as,

$$\oint \vec{B}\,\vec{d}l = \oint B\,dl = \oint B\,dl \quad .... (iii)$$

vii. Also $\oint dl = 2\pi r$

From equation (iii),

$$\oint \vec{B}.\vec{d}l = B\,(2\pi r) \quad .... (iv)$$

viii. From equation (i) and (iv), we have,

$B\,(2\pi r) = \mu_0 N I$

$$\therefore \quad B = \frac{\mu_0 NI}{2\pi r} \quad .... (v)$$

ix. If 'n' is the number of turns per unit length of toroid then $n = \dfrac{N}{2\pi r}$ .... (vi)

x. From equation (v) and (vi), we have,

$B = \mu_0\, nI$ .... (vii)

Equation (v) and (vii) both represent magnetic induction at a point along the axis of toroid.

Q.6. State Ampere's circuital law. Obtain an expression for magnetic induction along the axis of toroid. [Mar 14]

Ans: Refer Q.2 and Q.5

Note:

1. Line integral of magnetic field over any closed circular path is independent of the radius of circular path.
2. Ampere's law is true for steady current only.
3. Magnetic induction at a point near the end point of a solenoid is $\dfrac{\mu_0 nI}{2}$.
4. For a solenoid having core material of relative permeability 'μ_r', magnetic induction at a point inside it is,
   $\mu_0\mu_r\, nI = \mu nI$
5. Magnetic induction at a point on the circular path changes with the change in radius of the circular path.
6. Magnetic field of the toroid exists only within the cross section of the toroid and it is not uniform.

14.2 : Moving Coil Galvanometer (M.C.G.)

Q.7. State principle of M.C.G. With the help of neat labelled diagram, describe construction and working of a moving coil galvanometer. [Oct 03, 08]

OR

Explain the construction and working of a moving coil galvanometer. Hence show that a current flowing through it is directly proportion,al to the deflection. [Oct 98]

Ans: Principle of M.C.G:

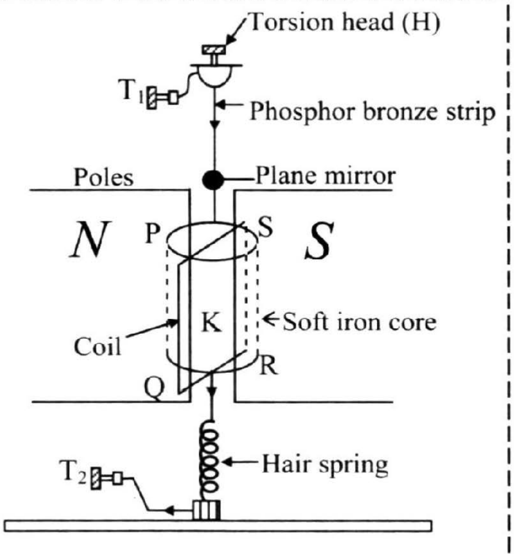
When a coil carrying an electric current is suspended in a uniform magnetic field, a torque acts on it. This torque tends to rotate the coil about the axis of suspension so that the magnetic flux passing through the coil is maximum.

Construction:

i. It consists of rectangular coil PQRS made up of large number of turns of thin insulated copper wire. This coil is wound on a light aluminium frame, which makes the galvanometer 'dead beat'.

ii. The coil is suspended between two strong concave pole pieces of horse shoe magnet, so that it can rotate freely in radial magnetic field set up between two poles pieces.

iii. A soft iron cylindrical core C, is situated coaxially to the cylindrical gap between pole pieces. This cylinder remains stationary and does not rotate with the coil.



Moving coil galvanometer

iv. The core performs two functions:

a. It makes field radial and uniform.

b. It increases the magnetic flux.

v. The coil is suspended by a phosphor bronze fibre F, so as to rotate freely about the axis of cylindrical gap. The fibre serves two purposes:

a. It serves as the inlet or outlet for the current.
b. It provides the restoring couple to the coil.

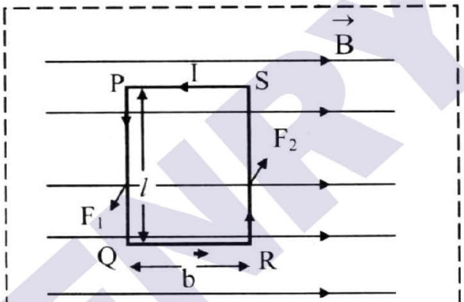
vi. The helical spring H serve as the inlet or outlet for the current and also saves the coil from mechanical shocks. The current enters the coil through F and leaves through the spring H placed at the bottom.

vii. A small plane mirror M is attached to the fibre F. As the coil rotates, the fibre gets twisted and M also gets rotated by some angle. The angle of rotation of the coil is measured by using a lamp and scale arrangement.

viii. In lamp and scale arrangement, a beam of light is made to fall on the mirror. The beam reflected from M is received on the plastic scale as a bright spot. When M rotates, the bright spot shifts on the plastic scale.

Working:

i. Suppose that rectangular coil PQRS is kept in uniform magnetic field of induction 'B'. Let 'n' be the number oftums of the coil with 'l' as its length and 'b' as its breadth. The current 'I' is passed through it in anti clockwise direction.



Torque acting on a rectangular coil

ii. The forces on QR and SP are equal to .... zero because they are parallel to $\vec{B}$.

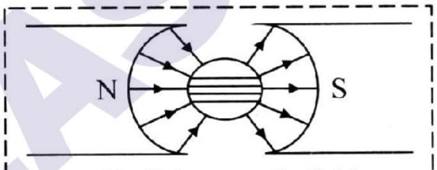
iii. Force on PQ,
$F_1 = nIBl$ (normally outwards)
Force on RS,
$F_2 = nIBl$ (normally inwards)

iv. Two forces F_1 and F_2 are equal in magnitude but opposite in direction and act at different points. Hence these forces constitute a torque (c) and rotate the coil.

v. Magnitude of torque is given by,
τ = Magnitude of one of the force × perpendicular distance between these parallel forces
$\therefore$ $\tau = (nBIl)(b) = nBI(lb)$
$\therefore$ $\tau = nBIA$
where, $A = lb$ = area of rectangular coil PQRS. .

vi. This torque deflects the coil hence it is called deflecting torque.
It is given by,
$\tau_d = nBIA$ .... (i)
This" torque causes the pointer attached to the coil to deflect and move on a graduated scale.

vii. As the coil is deflected, the phosphor bronze wire is twisted. This twist in phosphor bronze wire provides restoring or controlling torque.



Radial magnetic field

viii. This restoring torque is directly proportional to the deflection of the coil.
i.e. $\tau_1 \propto \theta$
$\tau_r = C\theta$ .... (ii)
where, the constant of proportionality C is called twist constant or restoring torque per unit twist.

ix. For equilibrium of the coil, $\tau_d = \tau_r$
$\therefore$ $nBIA = C\theta$

$$\therefore \quad I = \left(\frac{C}{nAB}\right)\theta \quad .... (iii)$$

Equation (iii) represents the current flowing through M.C.G.

x. For a given M.C.G., n, B, A are constant and for given suspension fibre C = constant.

$$\therefore \quad \frac{C}{nAB} = k = \text{constant}$$

$I = k\theta$
$I \propto \theta$
Hence, current flowing through galvanometer is proportional to deflection produced in it.

Q.8. Show that current flowing through the coil

of the moving coil galvanometer is directly proportional to the deflection of coil.

OR

Show that the current flowing through a moving coil galvanometer is directly proportional to the angle of deflection of coil. [Oct 14]

Ans: Refer Q.7 (Working)

Q.9. Give the construction of a suspended coil type moving coil galvanometer. [Mar 09]

Ans: Refer Q.7 (Construction)

Q.10. State four advantages of M.C.G.

Ans: Advantages of M.C.G:

i. It is not affected by strong magnetic field.
ii. It has high torque/weight ratio.
iii. It is very accurate and reliable.
iv. Its scales are uniform.

Q.11. State four disadvantages of M.C.G.

Ans: Disadvantages of M.C.G:

i. Changes in temperature affect restoring torque.
ii. Restoring torque cannot be easily changed.
iii. There is possibility of damage of phosphor bronze wire suspension and hair helical springs arising due to severe stress.
iv. Instrument cannot be used for alternating current (a.c) measurement.

Q.12. State the main uses of permanent magnet moving coil (PMMC) galvanometer.

Ans: Uses of PMMC galvanometer:

i. It is used as an ammeter to measure current.
ii. It is used as a voltmeter to measure P.D between two points.
iii. It is used as flux meter.
iv. It is used in ballistic galvanometer.

Q.13. What will happen, if the magnetic field in moving coil galvanometer is not radial?

Ans: i. If the magnetic field is not radial, the deflection produced in the coil is not directly proportional to the current passing through the galvanometer. This will result in the linear scale of measurement. The linear scale cannot be used for the current measurement.

ii. This is overcome by producing radial magnetic field. In radial magnetic field, the plane of the coil is always parallel to the magnetic lines of force, all the time whatever may be the position of the coil.

14.3 : Ammeter

Q.14. What is an ammeter?

Ans: i. Ammeter is an electrical device which is used to measure current flowing through any branch of an electric circuit.

ii. It is a shunted permanent magnet moving coil galvanometer.

iii. An ideal ammeter has zero resistance, but a real ammeter has little and finite resistance.

iv. It is always connected in series with the branch through which the current is to be measured.

v. It measures the current in unit ampere (A) or milliampere (mA).

Q.15. Explain the need to convert a galvanometer into an ammeter.

Ans: i. A galvanometer has finite internal resistance. When it is connected in the circuit, it changes the value of current flowing through it. Hence, M.C.G cannot measure the value of current correctly.

ii. A galvanometer is a highly sensitive instrument which gives full scale deflection for very small values of current of the order of 10 mA. Hence, high strength currents cannot be measured with the help of a galvanometer.

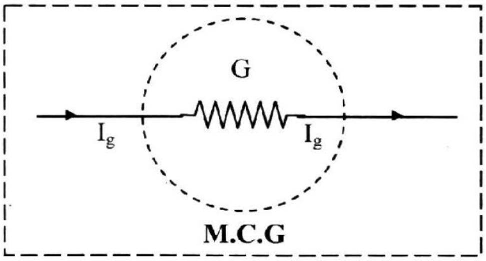
iii. If larger current is sent through the coil of galvanometer then coil may bum due to excessive heat.

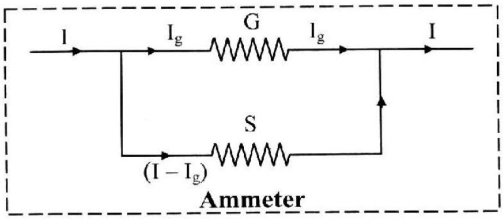
iv. To overcome the above demerits, low resistance (shunt) is connected in parallel with the coil of M.e.G.

Q.16. Explain how a moving coil galvanometer is converted into an ammeter. Derive the necessary formula. [Mar 12]

Ans: i. To use a M.C.G as an ammeter, its resistance should be reduced to a desired value and arrangement should be provided to measure large currents. This is achieved by connecting a shunt (low resistance) in parallel to the coil of M.C.G.

ii. The value of shunt is adjusted so that when current I flows, only the part Ig of the current passes through the coil of M.C.G and remaining part $(I - I_g) = I_s$ flows through shunt S.





iii. Let 'G' be the resistance of the galvanometer coil and 'I_g' be the maximum current, which can be passed through it for full-scale deflection.

iv. Let 'S' be the resistance of the shunt connected in parallel.
As resistances S and G are in parallel,

∴ P.D across S = P.D across G

∴ $I_s S = I_g G$ .... (i) (From Ohm's law)

∴ $(I - I_g) S = I_g G$

∴ $S = \left(\dfrac{I_g}{I - I_g}\right) G$ .... (ii)

This expression gives the value of shunt resistance that should be connected in parallel with moving coil galvanometer so as to convert it into an ammeter.

Note:
If the current 'I' is 'n' times the original current 'I_g', then I = nIg

i. $S = \left(\dfrac{I_g.G}{nI_g - I_g}\right)$

∴ $S = \dfrac{G}{n - I}$

ii. Potential difference across S = Potential difference across G,
$I_s S = I_g G$

∴ $\dfrac{I_s}{I_g} = \dfrac{G}{S}$

∴ $\dfrac{I_s}{I_g} + 1 = \dfrac{G}{S} + 1$

∴ $\dfrac{I_s + I_g}{I_g} = \dfrac{G + S}{S}$

∴ $\dfrac{I}{I_g} = \dfrac{G + S}{S}$ $[\because I = I_g + I_s]$

∴ $I_g = \left(\dfrac{G}{G + S}\right) I$

Similarly, $I_s = \left(\dfrac{G}{G + S}\right) I$

Q.17. What is shunt? State the advantages of using a shunt to convert galvanometer into ammeter.

Ans: Shunt:
Shunt is a low resistance, connected in parallel with the electric circuit.

Advantages of using shunt:

i. It diverts a large part of total current by providing an alternate path to flow of current. Thus, the instrument can be protected from damage.

ii. It increases the range of an ammeter.

iii. It decreases the resistance between the points to which it is connected.

Note:

1. Shunt resistors are made up of manganin which has zero temperature coefficient.
2. On connecting shunt in parallel to galvanometer coil, its equivalent resistance becomes less than the shunt resistance.

$$R = \frac{SG}{S + G}$$

3. The resistance of an ideal ammeter is zero.

Q.18. What will happen if shunt resistance in ammeter has a large value? How the hazard arising in such case can be rectified?

Ans: i. In an ammeter, if shunt resistance has large value, then shunt will draw lesser current than the current flowing through galvanometer. A galvanometer is constructed to draw less current. A large current flow will cause the coil to turn through large angle causing a large deflection and hence damage to the M.C.G.

ii. Secondly large current in galvanometer will produce excessive heat which may also damage the galvanometer.

iii. Ammeter is an instrument which measures current. Practically, an ammeter has low resistance to measure current accurately. An ideal ammeter has zero resistance.

iv. By connecting a shunt of suitable value parallel to ammeter of high resistance, one can measure the current accurately.

14.4 : Voltmeter

Q.19. What is voltmeter?

Ans: i. A permanent magnet moving coil instrument in series with high resistance is called a voltmeter.

ii. It is used to measure the potential difference between two points of an electric circuit.

iii. It is always connected in parallel to the branch across which the potential difference is to be measured.

iv. It gives magnitude of potential difference in volt (V).

v. An ideal voltmeter has infinite resistance so when it is connected between two points in a circuit, there is no change in value of current.

Q.20. Explain the need to convert a galvanometer into voltmeter.

Ans: i. Moving coil galvanometer is very delicate and can give full scale deflection for current of the order of 10 mA or when a small potential difference is applied across its terminals.

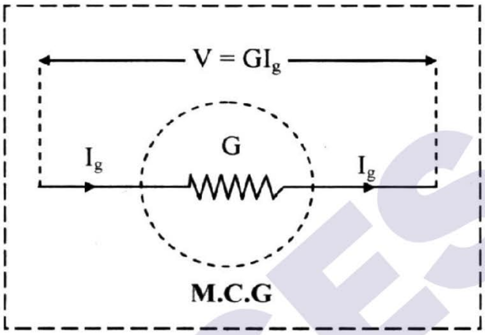
ii. Hence to measure large potential difference, effective resistance of instrument should be high. This is achieved by connecting high resistor in series with moving coil galvanometer.

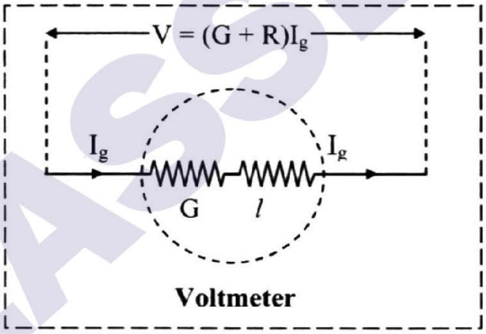
iii. If large potential difference is applied across the terminals of moving coil galvanometer, it may result in burning of the coil, due to excessive heat produced.

iv. The moving coil galvanometer will be protected from such a probable damage, if high resistance is connected in series with it.

Q.21. Explain how moving coil galvanometer can be converted into a voltmeter. [Mar 08] Derive the necessary formula.

Ans: i. To use a M.C.G as a voltmeter, its resistance should be increased to a desired value and an arrangement should be provided to measure large potential difference. This is achieved by connecting a high resistance in series with the M.C.G.





ii. Let 'G' be the resistance of the galvanometer coil and 'I_g' be the maximum current which can be passed through the galvanometer coil for fullscale deflection.

iii. Let 'V' be the potential difference to be mea ured.

Let 'R_s' be the resistance connected in series with the galvanometer coil.

iv. From Ohm's law,

$V = I_g (G + R_s)$

$$G + R = \frac{V}{I_g}$$

$$\therefore \quad R = \frac{V}{I_g} - G$$

Knowing V, I_g and G, value of R_s can be determined.

Note:

1. If 'V_1' is the p.d between the galvanometer coil when the galvanometer shows full scale deflection, then $V_1 = I_g G$.
2. When the galvanometer is converted into a voltmeter to read voltage 'V' then,

$V = nV_1 = nI_g G$

In this case,

$$R_s = \frac{nI_gG}{I_g} - G = G(n-1)$$

n is called multiplying power of the shunt.

3. Addition of the shunt increases voltage measuring capacity of the galvanometer.

Q.22. State the functions of high resistance in voltmeter. Also discuss a drawback of voltmeter.

Ans: i. Functions of high resistance in voltmeter:

a. To increase the effective resistance of galvanometer.
b. To increase the range of voltmeter.
c. To protect the galvanometer from damage due to large current.

ii. Drawback of voltmeter:

Since large value resistance with high precision is not easily available, voltmeter of high voltage range cannot be obtained.

Q.23. Distinguish between ammeter and voltmeter.

Ans:

No.	Ammeter	Voltmeter
i.	It measures current in the circuit.	It measures potential difference.
ii.	It is connected in series.	It is connected in parallel.
iii.	It has low effective resistance.	It has high effective resistance.
iv.	Resistance of ideal ammeter is zero.	Resistance of ideal voltmeter is infinite.

Q.24. What will happen, if resistance connected in series in voltmeter has a low value? How the hazard in this case can be rectified?

Ans: i. Voltmeter is always connected in parallel to the conductor for the measurement of potential difference across the conductor. Due to low resistance of the shunt, it will draw more current and hence lesser current will flow through the galvanometer. This will decrease potential difference across the conductor.

ii. When galvanometer is converted into voltmeter, the resistance of voltmeter is very large as compared to the resistance of galvanometer from which it is obtained.

iii. Ideally, voltmeter should have infinite resistance because practically it should draw any current from the circuit. Hence potential difference across the conductor will not decrease.

iv. By connecting proper value of shunt resistance connected in series with low resistance voltmeter, the voltmeter can be made proper for the measurement of potential difference.

14.5 : Sensitivity and accuracy of a moving coil galvanometer

Q.25. What is sensitivity of M.C.G?

Ans: Sensitivity of M.C.G:

i. A moving coil galvanometer is said to be sensitive, if it gives larger change in deflection for smaller change of current through it.

ii. Let I and I + dI be initial and final value of current flowing through coil of moving coil galvanometer.
Let θ and $\theta + d\theta$ be the deflections of coil for the current I and I + dI flowing through galvanometer.

iii. The deflections of coil of M.C.G changes by an amount of '$d\theta$', when current through it changes by an amount 'dI'.

iv. The ratio $\frac{d\theta}{dI}$ is called sensitivity of a moving coil galvanometer.

Thus, sensitivity of M.C.G, $S_i = \frac{d\theta}{dI}$.

Q.26. Define current sensitivity of a moving coil galvanometer. Derive an expression for it. Hence discuss the factors on which sensitivity of M.C.G depends.

OR

Obtain the expression for current sensitivity of a moving coil galvanometer.

[Feb 13]

Ans: Definition:

Deflection produced per unit current in the coil of MC.G is called current sensitivity of moving coil galvanometer.

It I.S gi.ven by, $S_i = \frac{d\theta}{dI}$

Unit: Radian/ ampere

Expression for current sensitivity:

i. Current flowing through moving coil galvanometer is given by,

$$I = \left(\frac{C}{NAB}\right)\theta \qquad ...(i)$$

where, C = twist constant
N = number of turns in the coil of M.C.G
A = area of the coil
B = magnetic induction

ii. Differentiating both sides of equation (i), we get,

$$dI = \left(\frac{C}{NAB}\right)d\theta$$

$$\therefore \quad \frac{d\theta}{dI} = \frac{NAB}{C}$$

$$\therefore \quad S_i = \frac{NAB}{C} \qquad ...(ii)$$

Equation (ii) represents current sensitivity of M.C.G.

Factors affecting sensitivity of M.C.G:
Sensitivity of M.C.G depends on the following:
i. Number of turns in rectangular coil (N).
ii. Magnetic induction of magnetic field (B).
iii. Area of rectangular coil (A).
iv. Twist constant of phosphor bronze wire suspension (C).

Q.27. State the conditions to increase the sensitivity of a moving coil galvanometer. **[Mar 98]**

Ans: Conditions to increase the sensitivity of a M.C.G:
Sensitivity of M.C.G is given by,

$$S_i = \left(\frac{NAB}{C}\right)$$

From formula it is clear $S_i \propto nAB$ and $S_i \propto \frac{1}{C}$

Thus sensitivity of M.C.G can be increased by,
i. increasing number of turns (N) of the coil
ii. increasing magnetic induction of magnetic field (B) by using a strong magnet.
iii. increasing area of coil (A).
iv. decreasing restoring torque per unit angular displacement (C).

Q.28. Sensitivity of M.C.G can be increased to a certain limit but cannot be increased beyond it. Justify the above statement.

Ans: i. From the relation, $S_i = \left(\frac{NAB}{C}\right)$, it is concluded that current sensitivity of M.C.G can be increased by increasing number of turns, area of the coil, magnetic induction of the coil and decreasing torque per unit twist.
ii. To increase B, a powerful magnet should be used but it may make the instrument very heavy (bulky).
iii. If n and A are increased, the weight of the coil increases and to support it a thick suspension fibre would be required. However, for a small value of C, the suspension fibre must be thin.
iv. By increasing number of turns of the coil, the area of the coil cannot be measured accurately.
v. This consideration shows that sensitivity of a moving coil galvanometer can be increased to some extent, there is a limit beyond which it cannot be increased.

Q.29. Explain how the accuracy of a moving coil galvanometer is increased.

Ans: i. A moving coil galvanometer is said to be more accurate, if the relative error in current $\left(\frac{dI}{I}\right)$ is less and vice-versa.
ii. When deflection 'θ' is measured, there is some error in deflection '$d\theta$' which leads to an error 'dI' in the measurement of current 'I'.
iii. Current through the galvanometer is given by, $I = \left(\frac{C}{NAB}\right)\theta$ .... (i)

where, C = torque per unit twist of suspension fibre
N = number of turns in the coil
B = magnetic induction produced by the coil of M.C.G
A = area of the coil

iv. On differentiating both sides of equation (i), we have,

$$dI = \left(\frac{C}{NAB}\right)d\theta \qquad .... (ii)$$

v. Dividing equation (ii) by equation (i), we get, $\frac{dI}{I} = \frac{d\theta}{\theta}$

$\frac{dI}{I}$ is the fractional or relative error in the measurement of current and $\frac{d\theta}{\theta}$ is the fractional error in the measurement of deflection.

vi. Thus, for greater accuracy of M.C.G, $\frac{dI}{I}$ should be small. For this, deflection θ should be as large as possible. For large deflection of a given current, lamp and scale arrangement is used.

vii. Also, for large deflection n, B and A should be large and C should be small.
Hence accuracy of M.C.G varies directly with N, B and A but varies inversely with C.

Note:

1. Suspension fibre in a galvanometer is made of phosphor bronze because it has very small value of C.
2. In very sensitive galvanometer, quartz fibre is used as suspension fibre.

Q.30. What are the advantages of M.C.G?

Ans: i. M.C.G contains strong magnetic field of the magnet as compared to the earth's magnetic field. Hence no previous adjustment of the galvanometer with respect to the earth's magnetic field is required.

ii. M.C.G can be made very sensitive by adjusting number 'of turns, area of coil and twist constant of suspension fibre.

iii. Linear scale can be used to measure the current since it can be adjusted for direct proportionality between the deflection and current.

iv. The coil of M.C.G comes to rest quickly when current passing through it is stopped.

10.6 : Cyclotron

Q.31. What is cyclotron? Explain the principle, construction and working of cyclotron.

Ans: Cyclotron:

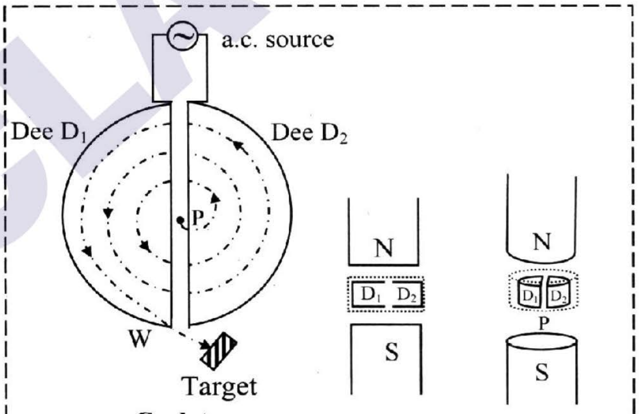
i. Cyclotron is a circular particle accelerator, which utilizes a magnetic field to bend charged particles into a circular path and electric field to accelerate them to high velocities.

ii. In cyclotron, positive ions cross again and again the same alternating electric field and thereby gain energy. It is achieved by making them to move along the spiral circular paths under the action of a strong magnetic field.

iii. Cyclotron is also called magnetic resonance accelerator, since its operation is based on the principle of resonance between applied electric and magnetic fields.

Principle:

When a positively charged particle moves perpendicular to uniform magnetic field again and again with a periodic time and is accelerated continuously by high frequency electric field, it traces a spiral path of increasing radius. The positively charged particle is accelerated to high speed and gains sufficient large amount of energy.



Cyclotron **2-D diagram** **3-D diagram**

Construction:

i. It consists of two D shaped hollow semicylindrical metallic chambers D_1 and D_2. These two chambers are called as dees. The two dees are placed horizontally with a small gap separating them. These two dees are kept in a steel box containing gas at a low pressure about 10^{-3} mm of Hg.

ii. The dees are connected to a high frequency oscillator due to which a high alternating voltage (10^4 V, 10^7 Hz) is applied between them. The steel box is placed between the poles of a strong electromagnet. The magnetic field is perpendicular to the plane of the dees. A source P of positive ions is kept at the centre of the dees.

iii. In a cyclotron, an electric field is used to accelerate a charged particle while a magnetic field is used to produce circular motion of the particle.

Working:

i. Suppose a positively charged particle is produced at P at an instant when the dee D_1 is at a positive potential and the dee D_2 is at a negative potential. The positively charged particle is accelerated towards the dee D_2.

ii. When it enters into the dee, there is no electric field inside the dee. Thus ions are only in magnetic field produced by the electromagnet. Hence the magnetic field 'Causes the particle to move along a circular path inside the dee D_2.

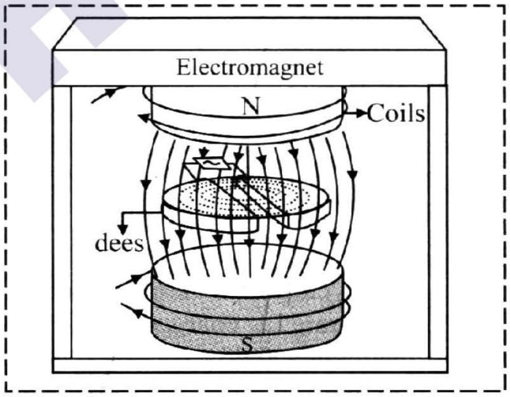
iii. After moving along a semicircle in the dee D_2, the particle again enters the gap between the dees. At that instant, the electric field reverses its direction so that the dee D_1 becomes negative and the dee D_2 becomes positive.

iv. Therefore, the particle is accelerated towards D_1 with increasing speed, and hence inside D_1 the particle moves along a semicircle of greater radius. This process continues till the particle reaches the periphery of the dee system, where the radius of the circular path becomes equal to the radius of the dees.

v. Alternately highly energetic positive ions escape from the window (W) in either of the dees and strike the target T.

Q.32. Draw a neat labelled diagram of a cyclotron showing a particle beam accelerated from center by dees.

Ans:



Q.33. Derive an expression for velocity of a charged particle in a cyclotron. Hence show that velocity of charged particle in a cyclotron varies directly with radius of circular path.

Ans: Expression for velocity of a charged particle:

i. Let,
v = velocity of charged particle
r = radius of circular path
B = magnetic field
q = charge on particle

ii. When a positively charged particle with a charge 'q' moves at right angle to the magnetic field, a force due to magnetic field acts on the particle which is given by,
$F = q vB \sin\theta$, But $\theta = 90°$

$\therefore$ $F = qvB$

iii. This force provides the centripetal force (mv^2/r) to the charged particle to move in a circular path of radius r.

$\therefore$ Centripetal force = Force due to magnetic field

$$\therefore \frac{mv^2}{r} = qvB$$

$$\therefore r = \frac{mv}{qB}$$

$$\therefore v = \frac{qB}{m}r \quad \text{...(i)}$$

This is required formula for velocity of charged particle.

iv. In equation (i) m, q and B are constant

$\therefore$ $r \propto v$

Thus, the radius of the circular path is directly proportional to the speed of the particle.

Q.34. Show that time taken by a charged particle to move along a semicircular path does not depend on the speed and radius of semicircular path.

Ans: i. The time taken by the particle to complete the semicircular path inside the dee is given by,

$$t = \frac{\text{distance}}{\text{speed}} = \frac{\pi r}{v}$$

where, πr = circumference of semicircular path

ii. $t = \frac{\pi}{v} \times r$

$t = \frac{\pi}{v} \times \frac{mv}{qB}$ $\left(\because r = \frac{mv}{qB}\right)$

$t = \frac{\pi m}{qB}$

If q = e, then $t = \frac{\pi m}{Be}$

iii. Since formula is independent of 'v' and :r'. Hence the time taken by the particle to move along a semicircular path does not depend on the speed of the particle or on the radius of the semicircular path.

Q.35. Show that cyclotron frequency for a charged particle is $\frac{qB}{2\pi m}$.

Ans: i. Let, q = magnitude of charge on charged particle
v = velocity of charged particle
t = time required to traverse semicircle
r = radius of semicircle.

ii. Time taken by charged particle to traverse semicircular path in the cyclotron is given by,

$t = \frac{\pi r}{v} = \frac{\pi}{v}.\frac{mv}{qB}$ $\left(\because r = \frac{mv}{qB}\right)$

$t = \frac{\pi m}{qB}$

Time required to traverse a circular path is,

$T = 2t = \frac{2\pi m}{qB}$

iii. Since magnetic resonance frequency is the reciprocal of its time period (T).

$f = \frac{1}{T} = \frac{1}{\frac{2\pi m}{qB}}$

$f = \frac{qB}{2\pi m}$

Q.36. Obtain an expression for kinetic energy of positively charged particle.

Ans: Expression for K.E of positively charged particle:

i. Let,
m = mass of charged particle
B = magnetic field induction
q = charge on the particle
r = radius of circular path
V_{max} = maximum velocity of charged particle inside the cyclotron

ii. Centripetal force required to move charged particle in circular path is given by,

$F_{CP} = \frac{mv^2_{max}}{r}$

iii. Force of magnetic induction due to charged particle is given by,
$F_B = q\,Bv_{max}$

iv. For equilibrium, $F_{CP} = F_B$

$\therefore \frac{mv^2_{max}}{r} = qBv_{max}$

$\therefore v_{max} = \frac{qBr}{m}$ ...(i)

v. Kinetic energy of charged particle is given by,

$K.E = \frac{1}{2}\, m\, v^2_{max}$

$= \frac{1}{2} m \left(\frac{qBr}{m}\right)^2$ [From equation (i)]

$\therefore K.E = \frac{q^2B^2r^2}{2m}$ .... (ii)

Equation (ii) represents kinetic energy of charged particle in the cyclotron .

Note:
Kinetic energy of electron in the cyclotron is given by, $K.E = \frac{e^2B^2r^2}{2m}$.

Q.37. State the main uses of cyclotron.

Ans: Uses of cyclotron:

i. It is used to produce high energetic particles from low voltage source.
ii. It is used to produce energy of several million volt.
iii. The high speed positively charged particles are used for the artificial disintegration of atomic nuclei.
iv. Cyclotron supplies a continuous stream of

accelerated ions.

Q.38. State the main limitations of cyclotron.
Ans: Limitations of cyclotron:

i. It cannot accelerate uncharged particles like neutrons.
ii. It cannot accelerate electrons, because it has a small mass and moves with very high speed. Therefore it cannot remain in phase with field.
iii. The charged particle cannot move with speed beyond certain limit in the cyclotron.
iv. It is not possible to design a machine capable of producing highly energetic particles having energy of the order of 500 MeV.

Note:

1. In cyclotron, hydrogen gas is used for producing protons, whereas helium gas is used for producing α -particles.
2. The positive ion executes spiral path, gaining kinetic energy every time on its crossing from one dee to another.
3. Positive ions in the cyclotron gain high velocity, escape through the window and bombard the target placed near window.

Summary :

1. Ampere's law gives the relation between tangential component of magnetic field at a point on a close curve and net current flowing through the area bounded by the curve.
2. Ampere's law states that the line integral of the resultant magnetic induction ($\vec{B}$) around any closed loop is equal to μ_0 times the total current 'I' enclosed by that loop i.e.

$$\oint \vec{B} \cdot \vec{d}l = \mu_0 I$$

3. Ampere's law is applied to determine magnetic induction at a point due to long straight conductor, solenoid, toroid, etc.
4. Magnetic induction at a point due to a long straight conductor at a distance 'r' is given by,

$$B = \frac{\mu_0}{4\pi}\frac{2I}{r}$$

5. Magnetic induction due to a long straight solenoid is given by, $B = \mu_0 nI$.
6. In a moving coil galvanometer, the current is directly proportional to the angle of deflection and is given by, $I = \frac{C\theta}{nAB}$.
7. M.C.G can be converted into ammeter by connecting a low value resistance in parallel with it and this resistance is determined by,

$$S = \left(\frac{I_g}{I - I_g}\right)G.$$

8. If M.C.G is converted into ammeter to increase its range n times of the original range then a shunt resistance is connected in parallel with circuit. It is given by,

$$S = \left(\frac{I_g}{nI_g - I_g}\right)G = \frac{G}{n-1}.$$

9. M.C.G can be converted into voltmeter by connecting a high value resistance in series with it and this resistance is given by,

$$R_s = \frac{V}{I_g} - G .$$

10. If M.C.G is converted into voltmeter to increase its range to 'n' times of the original value then resistance is connected in series with the circuit. This resistance is given by a suitable

$$R = \frac{nV_g}{V_g / G} - G = nG - G = G\,(n-1).$$

11. In a galvanometer, deflection per unit current is called current sensitivity. It is given by,

$$S_i = \frac{NAB}{C} .$$

12. Cyclotron is a device which is used to accelerate charged particles. Electric field accelerates positively charged particles and magnetic field enables the charged particles to move in a circular path.

Formulae :

1. **Force on a current carrying conductor:**
   $F = IlB \sin\theta$
2. **Torque acting on the coil :**
   $\tau = nAIB \cos\theta$

3. Magnetic induction at a point outside a long straight conductor:

$$B = \frac{\mu_0}{4\pi}\frac{2I}{r}$$

4. Magnetic induction due to long solenoid:

i. At a point inside the solenoid,
$B = \mu_0 nI$

ii. At a point near the end of solenoid,

$$B_{end} = \frac{1}{2}\ \mu_0 ni$$

where, $n = \frac{N}{l}$ = turns per unit length of solenoid

5. Magnetic induction due to toroid:

$$B = \mu_0 nI = \frac{\mu_0}{4\pi}\frac{2NI}{r}$$

where, $\frac{N}{2\pi r}$ = turns per unit length of toroid

6. Moving coil galvanometer (M.C.G):

i. Deflecting torque acting on coil:
$\tau_d = nIAB\cos\theta$

ii. Restoring torque: $\tau_r, = k8\,\theta$

7. Current flowing through galvanometer:

$$I = \left(\frac{C}{NAB}\right)\theta$$

8. Deflection in moving coil galvanometer:

$$\theta = \frac{NIAB}{C}$$

9. Current sensitivity of M.C.G :

$$S_i = \frac{d\theta}{dI} = \frac{NAB}{C}$$

10. Ammeter :

i. $I = I_s + I_g$ ii. $I_s S = I_g G$

iii. $S = \frac{GI_g}{I - I_g}$ iv. $S = \frac{G}{n-1}$

11. Voltmeter :

i. $R = \frac{V}{I_g} - G = G(n-1)$

ii. $I_g = \frac{V}{R+G}$

12. Radius of circular path in a cyclotron:

$$r = \frac{mv}{qB}$$

13. Time period for charged particle to complete circular path:

$$T = \frac{2\pi m}{qB}$$

14. Frequency of charged particle:

$$f = \frac{1}{T} = \frac{qB}{2\pi m}$$

15. K.E of charged particle:

$$K.E = \frac{(qBr)^2}{2m}\ \text{joule} = \frac{(qBr)^2}{2em}\ \text{eV}$$

where, $V_{max} = \frac{qBR}{m}$

Solved Problcms :

Example 1

A long straight solid conductor of radius 5 cm carries a current of 2 A which is uniformly distributed over its circular cross-section. Find the magnetic field induction at a distance of 3 cm from the axis of the conductor.

Solution:

Given : R = 5 cm = 0.05 m, I = 2 A, r = 3 cm = 0.03 m

To find : Magnetic field induction (B)

Formula : $\oint \vec{B}.\vec{d}l = \mu_0 I$

Calculation : Current enclosed by circular path of radius r is given by,

$$I' = \frac{I}{\pi R^2} \times \pi r^2 = \frac{Ir^2}{R^2}$$

From formula,

$$\oint \vec{B}.\vec{d}l = \mu_0 I'$$

$$\therefore \quad B \times 2\pi r = \mu_0 \frac{Ir^2}{R^2}$$

$$\therefore \quad B = \frac{\mu_0}{2\pi}\frac{Ir}{R^2} = \frac{\mu_0}{4\pi} \times \frac{2Ir}{R^2}$$

$$\therefore \quad B = \frac{10^{-7} \times 2 \times 2 \times 0.03}{(0.05)^2}$$

$$\therefore \quad B = \mathbf{4.8 \times 10^{-6}\ T}$$

Ans: Magnetic field induction at the given distance from the conductor is **4.8×10^{-6} T**.

Example 2

A long solenoid of length 1 m has 1000 turns of wire closely wound on it. If the current in the winding is 3 A, calculate the magnetic field at the centre of solenoid.

Solution:

Given : l = 1 m, N = 1000, I = 3 A

To find : Magnetic field (B)

Formula : $B = \mu_0 nI$

Calculation : Number of turns per unit length

$$n = \frac{N}{l} = \frac{1000}{1} = 1000 \text{ turns/ m}$$

From formula,

$$B = 4\pi \times 10^{-7} \times 1000 \times 3$$
$$= 4 \times 3.14 \times 3 \times 10^{-4}$$
$$= 12.56 \times 3 \times 10^{-4}$$
$$= 37.68 \times 10^{-4}$$
$$\therefore \quad B = 3.768 \times 10^{-3}\ \text{Wb/m}^2$$

Ans: Magnetic field at the centre of the solenoid is **3.768×10^{-3} Wb/m²**.

Example 3

A solenoid of length 0.5 m has radius of 1 cm and is made up of 500 turns. It carries a current of 5 A. What is the magnitude of the magnetic field inside the solenoid? (NCERT)

Solution:

Given : l = 0.5 m, r = 1 cm = 10^{-2} m, N = 500, I = 5 A

To find : Magnetic field (B)

Formula : $B = \mu_0 nI$

Calculation : Since , $n = \frac{N}{l}$

From formula,

$$B = \mu_0 \times \frac{N}{l} \times I$$

$$= 4\pi \times 10^{-7} \times \frac{500}{0.5} \times 5$$

$$\therefore \quad B = \mathbf{6.28 \times 10^{-3}\ T}$$

Ans: Magnitude of the magnetic field inside the solenoid is **6.28×10^{-3} T**.

Example 4

A toroid has a core (non ferromagnetic material) of inner radius 25 cm and outer radius 26 cm around which 3500 turns of wire are wound. If the current in the wire is 11 A, what is the magnetic field (a) outside the toroid (b) inside the core of the toroid (c) in the cmpty space surrounded by the toroid? (NCERT)

Solution:

Given : r_1 = 0.25 m; r_2 = 0.26 m; N = 3500; I = 1.1 A

To find : Magnetic field

i. outside the toroid (Bout)
ii. inside the core of the toroid (B_{in})
iii. in the cmpty space surrounded by the toroid (B_{sp})

Formula : $B = \frac{\mu_0 NI}{l}$

where l = mean length of toroid

$$= 2\pi\frac{(r_1 + r_2)}{2}$$

Calculation :

i. Outside the toroid, the magnetic field is zero.

∴ $B_{out} = 0$

ii. From formula,

$l = n(r_1 + r_2) = \pi\ (0.25 + 0.26) = \pi \times 0.51$ m

∴ $B = \frac{(4\pi \times 10^{-7}) \times 3500 \times 11}{\pi \times 0.51}$

∴ B_{in} = **3.02×10^{-2} T**

iii. In the cmpty space surrounded by Toroid, the magnetic field is zero.

∴ B_{sp} = **0**

Ans: The magnetic field,

i. outside the toroid is zero.

ii. inside the core of the toroid is **3.02×10^{-2} T**.

iii. in the cmpty space surrounded by the toroid is zero.

Example 5

A rectangular coil in a moving coil galvanometer has 50 turns, each of length 5 cm and breadth 3 cm, which is suspended in a radial magnetic field of 0.050 Wb/m². The twist constant of suspension is 1.5 × 10⁻⁹ Nm/degree. Calculate the current through the coil which will deflect it through 30°.

Solution:

Given : $N = 50$, $C = 1.5 \times 10^{-9}$ Nm/degree,

$B = 0.05$ Wb/m², $\theta = 30°$,

$A = l \times b = 5 \times 3 = 15$ cm²

$= 15 \times 10^{-4}$m²

To find : Current (I)

Formula : $I = \frac{C\theta}{NAB}$

Calculation : From formula,

$I = \frac{1.5 \times 10^{-9} \times 30}{50 \times 15 \times 10^{-4} \times 0.05}$

∴ I = **1.2×10^{-5} A**

Ans: The current through the coil which will deflect it through 30° is **1.2×10^{-5} A**.

Example 6

A rectangular coil of wire of 50 turns, each of area 8 cnr', is suspended freely in a radial magnetic field of induction 2 × 10⁻² Wb/m². When a current of 5 mA is passed through the coil, it deflects through 60°. Find the torsional constant of the suspension fibre.

Solution:

Given : $N = 50$, $A = 8$ cm² $= 8 \times 10^{-4}$ m²

$B = 2 \times 10^{-2}$ Wb/m²,

$I = 5$ mA $= 5 \times 10^{-3}$ A, $\theta = 60°$

To find : Torsional constant (C)

Formula : $I = \frac{C\theta}{NAB}$

Calculation : From formula,

$C = \frac{NABI}{\theta}$

$= \frac{50 \times 8 \times 10^{-4} \times 2 \times 10^{-2} \times 5 \times 10^{-3}}{60}$

$= \frac{400}{60} \times 10^{-8}$

∴ C = **6.67×10^{-8} m/degree**

Ans: The torsional constant of the suspension fibre is **6.67×10^{-8} Nm/degree.**

Example 7

A rectangular coil of 100 turns, each of area 10 cm², hangs freely in a radial magnetic field. The coil deflects through 30° when a current of 5 μA is passed through it. If the torsional constant of suspension fibre is 25 × 10⁻⁹ Nm/radian, find the magnetic field.

Solution:

Given : $N = 100$,

$A = 10$ cm² $= 10 \times 10^{-4}$ m² $= 10^{-3}$ m²,

$\theta = 30° = \frac{\pi}{6}$ rad,

$I = 5\ \mu A = 5 \times 10^{-6}$ A,

$C = 25 \times 10^{-9}$ Nm/rad

To find : Magnetic field (B)

Formula : $I = \frac{C\theta}{NAB}$

Calculation : From formula,

$B = \frac{C\theta}{NAI}$

∴ $B = \frac{25 \times 10^{-9} \times \pi}{6 \times 100 \times 10^{-3} \times 5 \times 10^{-6}}$

∴ B = **0.026 Wb/m²**

Ans: Magnetic field of the rectangular coil is **0.026 Wb/m²**.

Example 8

Two moving coil meters, M_1 and M_2, have the following particulars:

$R_1 = 10\Omega$, $N_1 = 30$,
$A_1 = 3.6 \times 10^{-3}$ m², $B_1 = 0.25$ T,
$R_2 = 14\Omega$, $N_2 = 42$,
$A_2 = 1.8 \times 10^{-3}$ m², $B_2 = 0.50$ T (The spring constants are identical for the two meters). Determine the ratio of current sensitivities of M_2 and M_1. (NCERT)

Solution:

Given : $R_1 = 10\Omega$, $N_1 = 30$, $A_1 = 3.6 \times 10^{-3}$ m², $B_1 = 0.25$ T, $R_2 = 14\Omega$, $N_2 = 42$, $A_2 = 1.8 \times 10^{-3}$ m², $B_2 = 0.50$ T

To find : Ratio of current sensitivities $\frac{(S_i)_2}{(S_i)_1}$

Formula : $S_i = \frac{NAB}{C}$

Calculation : From formula,

$$\frac{(S_i)_2}{(S_i)_1} = \frac{N_2A_2B_2}{N_1A_1B_1}$$

$$= \frac{42 \times 1.8 \times 10^{-3} \times 0.5}{30 \times 3.6 \times 10^{-3} \times 0.25}$$

$$= \frac{7}{5}$$

$$\therefore \quad \frac{(S_i)_2}{(S_i)_1} = \mathbf{1.4 : 1}$$

Ans: The ratio of current sensitivities of M_2 and M_1 is **1.4 : 1**.

Example 9

A milliammeter gives a f.s.d for 25 mA and its resistance is 20Ω. How will you use it to measure a current of 500 mA?

Solution:

Given : $I_g = 25$ mA, $G = 20\Omega$, $I = 500$ mA

To find : Shunt resistance (S)

Formula : $S = \frac{GI_g}{I - I_g}$

Calculation : From formula,

$$S = \frac{20 \times 25}{500 - 25} = \frac{500}{475}$$

$$\therefore \quad S = \frac{20}{19}$$

$$\therefore \quad S = \mathbf{1.053}\ \Omega$$

Ans: A shunt resistance of **1.053 Ω** is connected in parallel.

Example 10

A galvanometer with a coil of resistance 40 ohm gives a full scale deflection for a current of 5 mA. How will you convert it into an ammeter of range 0 – 5A?

Solution:

Given : $G = 40\ \Omega$, $I_g = 5$ mA $= 5 \times 10^{-3}$ A, $I = 5$ A,

To find : Shunt resistance (S)

Formula : $S = \left(\frac{I_g}{I - I_g}\right) G$

Calculation : From formula,

$$S = \left(\frac{5 \times 10^{-3}}{5 - 5 \times 10^{-3}}\right) \times 40 = 0.04\,\Omega$$

$$\therefore \quad S = \mathbf{0.04}\,\Omega$$

Ans: A shunt resistance of 0.04 Ω is connected in parallel with the galvanometer.

Example 11

A resistance of 3 ohm is connected in parallel to a galvanometer of resistance 297 ohm. Find the fraction of current passing through the galvanometer.

Solution:

Given : $S = 3\ \Omega$, $G = 297\ \Omega$

To find : fraction of current $\left(\frac{I_g}{I}\right)$

Formula : $I_g G = (I - I_g) S$

Calculation : From formula,

$$\frac{G}{S} + 1 = \frac{I}{I_g}$$

$$\therefore \quad \frac{G + S}{S} = \frac{I}{I_g}$$

$$\therefore \quad \frac{I}{I_g} = \frac{S}{G + S} = \frac{3}{297 + 3}$$

$$\therefore \quad \frac{I}{I_g} = \frac{3}{300} = \left[\frac{3}{300} \times 100\%\right]$$

$$\therefore \quad \frac{I}{I_g} = \mathbf{1\ \%}$$

Ans: The fraction of current passing through the galvanometer is **1%.**

Example 12

A galvanometer has a resistance of 16 Ω and gives a full scale deflection when a current of 20 mA is passed through it. The only shunt resistance available is 0.04 Ω which is not appropriate to convert galvanometer into an ammeter. How much resistance should be connected in series with coil of galvanometer so that the range of ammeter is lOA?

Solution:

Let 'X' be the resistance connected in series with galvanometer. Since S is not sufficient for I = 10 A,

From the figure,

$$\frac{I}{I_g} = \frac{S}{(S+X)+S}$$

$$\therefore \quad (G+X)+S = \frac{I}{I_g}S$$

$$\therefore \quad (16+X)+0.04 = \frac{10}{2\times10^{-2}} \times 0.04$$

$$\therefore \quad (16+X+0.04) = 20$$

$$\therefore \quad X = 20 - 16.04$$

$$\therefore \quad X = \mathbf{3.96\,\Omega}$$

Ans: A resistance of **3.96 Ω** should be connected in series with coil of galvanometer.

Example 13

A galvanometer of resistance 50 Ω has a current sensitivity of 5 div/mA. The instrument has 25 divisions. How will you convert it into a voltmeter of range 0 – 50 V?

Solution:

Given: $G = 50\ \Omega$, $V = 50$ V,

$$I_g = \frac{25}{5} = 5 \text{ mA} = 5 \times 10^{-3} \text{ A}$$

To find: Resistance (R_s)

Formula: $R = \frac{V}{I_g} - G$

Calculation: From formula,

$$R_s = \frac{50}{5\times10^{-3}} - 50 = 10000 - 50$$

$$\therefore \quad R_s = \mathbf{9950\ \Omega}$$

Ans: A resistance of **9950 Ω** should be connected in series.

Example 14

A galvanometer coil has a resistance of 12 Ω and meter shows full scale deflection for a current of 3 mA. How will you convert the meter into a voltmeter of range 0 to 18 V? (NCERT)

Solution:

Given: $G = 12\ \Omega$, $V = 18$ V, $I_g = 3$ mA $= 3 \times 10^{-3}$ A

To find: Resistance (R_s)

Formula: $R = \frac{V}{I_g} - G$

Calculation: From formula,

$$R_s = \frac{18}{3\times10^{-3}} - 12$$

$$R_s = \mathbf{5988\ \Omega}$$

Ans: A resistance of 5988 Ω should be connected in senes.

Example 15

A voltmeter of resistance 500 Ω can measure a maximum voltage of 5 volt. How can it be made to measure a maximum voltage of 100 volt?

Solution:

Given: $G = 500\ \Omega$, $V = 100$ V, $V_g = 5$ V

To find: High resistance (R)

Formula: $R = G(n-1)$

Calculation: We know that,

$$n = \frac{V}{V_g} = \frac{100}{5} = 20$$

Now, using formula we get,

$$R = 500\,(20-1)$$

$$= 500 \times 19$$

$$\therefore \quad R = \mathbf{9500\,\Omega}$$

Ans: Given voltmeter can be made to measure a maximum voltage of 100 V by connecting a resistance of **9500 Ω** in series with it.

Example 16

Calculate the value of resistance needed to convert a moving coil galvanometer of 60 Ω into an ammeter of range 5 A which gives full scale deflection for a current of 50 mA and into voltmeter of range 0 – 50 V.

Solution:

Given : $G = 60\ \Omega$, $V = 50$ V, $I = 5$ A,
$I_g = 50$ mA $= 50 \times 10^{-3}$
A $= 5 \times 10^{-2}$ A

To find : i. Shunt resistance (S),
ii. Series resistance (R_s)

Formulae : i. $S = \dfrac{GI_g}{I - I_g}$

ii. $R_s = \dfrac{V}{I_g} - G$

Calculation : From formula (i),

$$S = \frac{60 \times 0.05}{5 - 0.05} = \frac{3}{4.95}$$

$\therefore$ $S =$ **0.6061 Ω**

From formula (ii),

$$R_s = \frac{50}{5 \times 10^{-2}} - 60$$

$\therefore$ $R_s = 1000 - 60$

$R_s =$ **940 Ω**

Ans: i. A shunt resistance of 0.6061 Ω is to be connected in parallel with given M.C.G.

ii. A resistance of 940 Ω is to be connected in series with given M.C.G.

Example 17

A galvanometer has a resistance of 25 Ω and gives a full scale deflection for a current of 10 mA. This galvanometer is to be modified to give ranges 12.5 A and 50 V. What are the resistances needed to achieve this? [Feb 2013 old course]

Solution:

Given : $G = 25\ \Omega$, $V = 50$ V, $I = 12.5$ A
$I_g = 10$ mA $= 10 \times 10^{-3}$
A $= 1 \times 10^{-2}$ A

To find : i. Series resistance (R_s)
ii. Shunt resistance (S)

Formula : i. $R_s = \dfrac{V}{I_g} - G$

ii. $S = \dfrac{GI_g}{I - I_g}$

Calculation : From formula (i),

$$R_s = \frac{50}{1 \times 10^{-2}} - 25$$

$\therefore$ $R_s = 5000 - 25$

$\therefore$ $R_s =$ **4975 Ω**

From formula (ii),

$$S = \frac{25 \times 1 \times 10^{-2}}{12.5 - 0.01}$$

$\therefore$ $S = \dfrac{0.25}{1249}$

$\therefore$ $S =$ **0.020 Ω**

Ans: i. A resistance of **4975 Ω** is to be connected in series with given galvanometer.

ii. A shunt resistance of **0.020 Ω** is to be connected in parallel with given galvanometer.

Example 18

A galvanometer carries a maximum current of 15 mA when a voltage of 0.75 V is applied to it. Convert this into a voltmeter to read upto 150 volt and into an ammeter to read up to 25 ampere.

Solution:

For voltmeter, $V = 150$ V and $V_g = 0.75$ V,
$I_g = 15$ mA $= 15 \times 10^{-3}$ A

$\therefore$ $n = \dfrac{V}{V_g} = \dfrac{150}{0.75} = 200$

Also $G = \dfrac{V_g}{I_g} = \dfrac{0.75}{15 \times 10^{-3}} = 50\ \Omega$

$\therefore$ $R = G(n - 1) = 50(200 - 1)$

$\therefore$ $R =$ **9950 Ω in series**

For ammeter, $I = 25$ A,
$I_g = 15$ mA $= 15 \times 10^{-3}$, A

$\therefore$ $n = \dfrac{I}{I_g} = \dfrac{25}{15 \times 10^{-3}} = 1667$

$\therefore$ $S = \dfrac{G}{n - 1} = \dfrac{50}{1667 - 1} = \dfrac{50}{1666} = 0.03\ \Omega$

$\therefore$ $S =$ **0.03 Ω in parallel**

Ans: i. A resistance of **9950 Ω** is to be connected in senes with given galvanometer.

ii. A shunt resistance of **0.03 Ω** is to be connected in parallel with given galvanometer.

Example 19

The combined resistance of galvanometer of resistance 1000 ohm and its shunt is 25 ohm. Calculate the value of shunt.

Solution:

Given : $G = 1000\ \Omega$, $R_{eq.} = 25\ \Omega$

To find : Shunt resistance (S)

Formula : $\frac{1}{R_{eq}} = \frac{1}{G} + \frac{1}{S}$

Calculation : From formula,

$$\frac{1}{S} = \frac{1}{R_{eq}} - \frac{1}{G} = \frac{G - R_{eq}}{R_{eq}.G}$$

$$\therefore \quad S = \frac{R_{eq}G}{G - R_{eq}}$$

$$\therefore \quad S = \frac{25 \times 1000}{1000 - 25} = \frac{25 \times 1000}{975}$$

$$\therefore \quad S = \mathbf{25.64\ \Omega}$$

Ans: The value of shunt resistance to be connected is **25.64 Ω**.

Example 20

The coil of a moving coil galvanometer has 100 turns, each of area 0.05 m². It is suspended in a radial magnetic field of induction 0.01 Wb/m². If the torque per unit twist of the suspension fibre is 5 × 10⁻⁹ Nm/degree, find the sensitivity of the galvanometer.

Solution:

Given : $N = 100$, $A = 0.05\ m^2$
$B = 0.01\ Wb/m^2$
$C = 5 \times 10^{-9}$ Nm/degree

To find : Sensitivity (S_i)

Formula : $S = \frac{NAB}{C}$

Calculation : From formula,

$$S_i = \frac{100 \times 0.05 \times 0.01}{5 \times 10^{-9}}$$

$$\therefore \quad S_i = \mathbf{10^7\ div/A}$$

Ans: The sensitivity of the galvanometer is **10^7 div/A**.

Example 21

A rectangular coil of a moving coil galvanometer contains 50 turns, each having area 12 cm², It is suspended in radial magnetic field of induction 0.025 Wb/m² by a fibre of twist constant 15 × 10⁻¹⁰ Nm/degree. Calculate the sensitivity of a moving coil galvanometer.

Solution:

Given : $N = 50$, $A = 12\ cm^2 = 12 \times 10^{-4}\ m^2$
$B = 0.025\ Wb/m^2$
$C = 15 \times 10^{-10}$ Nm/degree

To find : Sensitivity (S_i)

Formula : $S_i = \frac{NAB}{C}$

Calculation : From formula,

$$S_i = \frac{50 \times 12 \times 10^{-4} \times 0.025}{15 \times 10^{-10}}$$

$$\therefore \quad S_i = \mathbf{10^6\ div/A}$$

Ans: The sensitivity of a moving coil galvanometer is **10^6 div/A**.

Example 22

In a chamber, a uniform magnetic field of 6.5 G (1 G = 10⁻⁴ T) is maintained. An electron is shot into the field with a speed of 4.8 × 10⁶ m/s normal to the field. Obtain the frequency of revolution of an electron in its circular orbit. Does the answer depend on the speed of an electron?

Solution:

Given : $B = 6.5\ G = 6.5 \times 10^{-4}\ T$,
$v = 4.8 \times 10^6\ m/s$

To find : Frequency of revolution (f)

Formula : $f = \frac{eB}{2\pi m}$

Calculation : From formula,

$$f = \frac{1.6 \times 10^{-19} \times 6.5 \times 10^{-4}}{2 \times 3.14 \times 9.1 \times 10^{-31}}$$

$$\therefore \quad f = \mathbf{18\ MHz}$$

Ans: Frequency of revolution of the electron is **18 MHz.** No, frequency does not depend on the velocity of electron.

Example 23

A proton is accelerated in a cyclotron in which the magnetic induction is 0.6 Wb/m². Find the cyclotron frequency.

[Given: $m_p = 1.673 \times 10^{-27}$ kg, e = 1.6×10^{-19} C]

Solution:

Given : $B = 0.6\ Wb/m^2$,
$m_p = 1.673 \times 10^{-27}$ kg,
$e = 1.6 \times 10^{-19}$ C

To find : Frequency (f)

Formula : $f = \frac{qB}{2\pi m}$

Calculation : From formula,

$$f = \frac{1.6 \times 10^{-19} \times 0.6}{2 \times 3.14 \times 1.673 \times 10^{-27}}$$

$\therefore$ $f = \mathbf{9.13 \times 10^6\ Hz}$

Ans: The frequency of the cyclotron is **9.13×10^6 Hz**.

Example 24

In a cyclotron" magnetic field of 3.5 Wb/m² is used to accelerate protons. What should be the time interval in which the electric field between the Dees be reversed? [Mar 13] [Mass of proton = 1.67×10^{-27} kg, Charge on proton = 1.6×10^{-19} C].

Solution:

Given : $B = 3.5\ Wb/m^2$
$m_p = 1.67 \times 10^{-27}$ kg,
$e = 1.6 \times 10^{-19}$ C

To find : Time interval (t)

Formula : $t = \frac{\pi m_p}{B q_p}$

Calculation : From formula,

$$t = \frac{3.142 \times 1.67 \times 10^{-27}}{3.5 \times 1.6 \times 10^{-19}}$$

$t = \mathbf{0.9369 \times 10^{-8}\ s}$

OR

$t = \mathbf{9.369 \times 10^{-9}\ s}$

Ans: The time interval in which the electric field between the Dees be reversed is 9.369×10^{-9} s.

Example 25

A cyclotron's oscillator frequency is 10 MHz. What should be the operating magnetic field for accelerating protons? If the radius of its 'dees' is 60 cm, what is the kinetic energy (in MeV) of the proton beam produced by the accelerator?
[e = 1.6×10^{-19} C, $m_p = 1.67 \times 10^{-27}$ kg, 1 eV = 1.6×10^{-19} J] (NCERT)

Solution:

Given : $f = 10\ MHz = 10^7\ Hz$,
$r = 60\ cm = 0.6\ m$,
$e = 1.60 \times 10^{-19}$ C,
$m_p = 1.67 \times 10^{-27}$ kg

To find :
i. Magnetic field (B),
ii. Kinetic energy in MeV (K.E)

Formulae :
i. $f = \frac{eB}{2\pi m}$
ii. $K.E = \frac{e^2B^2r^2}{2m}$

Calculation : From formula (i),

$$B = \frac{2\pi mf}{e}$$

$$= \frac{2\pi \times 1.67 \times 10^{-27} \times 10^7}{1.6 \times 10^{-19}}$$

$\therefore$ $B = \mathbf{0.656\ T}$

From formula (ii),

$$K.E = \frac{(1.6 \times 10^{-19})^2 \times (0.656)^2 \times (0.6)^2}{2 \times 1.67 \times 10^{-27}}$$

$$KE = \frac{3.966 \times 10^{-39}}{3.34 \times 10^{-27}}$$

$K.E = 1.187 \times 10^{-12}$ J

$\therefore$ $K.E = \mathbf{7.42\ MeV}$

Ans: i. The operating magnetic field for accelerating protons is **0.656 T**.

ii. The kinetic energy of the proton beam produced is **7.42 MeV**.

Example 26

What is the radius of the path of an electron (mass 9×10^{-31} kg and charge 1.6×10^{-19} C) moving at a speed of 3×10^7 m/s in a magnetic field of 6×10^{-4} T perpendicular to it? What is its frequency? Calculate its energy in keY.
(1 eV = 1.6×10^{-19} J). (NCERT)

Solution:

Given : $m = 9 \times 10^{-31}$ kg,
$q = e = 1.6 \times 10^{-19}$ C,
$v = 3 \times 10^7$ m/s, $B = 6 \times 10^{-4}$ T

To find :
i. Radius of the path of electron (r)
ii. Frequency (f)
iii. Kinetic energy (KE)

Formula : i. $r = \frac{mv}{eB}$

ii. $f = \frac{eB}{2\pi m}$

iii. $K.E = \frac{e^2B^2r^2}{2m}$

Calculation : From formula (i),

$$r = \frac{9\times10^{-31}\times3\times10^{7}}{\left(1.6\times10^{-19}\times6\times10^{-4}\right)}$$

$\therefore$ r = **0.28 m**

From formula (ii),

$$f = \frac{1.6\times10^{-19}\times6\times10^{-4}}{2\times\pi\times9.1\times10^{-31}}$$

$\therefore$ f = **16.79 MHz**

From formula (iii),

$$K.E = \frac{(1.6\times10^{-19})^2\times(6\times10^{-4})^2\times(0.28)^2}{2\times9\times10^{-31}}$$

$$= \frac{7.225\times10^{-46}}{18\times10^{31}}$$

KE = 4.014×10^{-16} J

$\therefore$ KE = **2.51 keV**

Ans: i. The radius of ,the path of electron is **0.28m**.

ii. The frequency of the electron is **16.79 MHz**.

iii. The kinetic energy of the electron is **2.51 keV.**

EXERCISE :

Section A: Practice problems

1. A coil with effective area 0.05 m² has 50 turns and strength of radial magnetic field is 0.01 Wb/m². If torque per unit twist of the suspension is 5×10^{-9} Nm/degree, calculate sensitivity of the galvanometer.

2. A galvanometer having resistance of 9 Ω gives full scale deflection with 1 mA current. Calculate shunt resistance required to convert it to an ammeter reading current upto 1 A.

3. The combined resistance of the galvanometer of resistance 500 ohm and its shunt is 25 ohm. Calculate the value of the shunt.

4. A galvanometer of resistance 100 ohm gives a f.s.d. with a current of 2 mA. How will you use it to measure a voltage upto 5 volt?

5. A long solenoid carries a current of 1A. If the number of turns is 3000 per 0.6 m length of the solenoid, find the flux density at a point well inside the solenoid on its axis.

6. A cyclotron has an oscillator frequency 1.2×10^7 Hz and a dee radius of 2 m. Find the magnetic induction required to accelerate deuterons. [Mass of deuteron = 3.3×10^{-27} kg and charge on deuteron = 1.6×10^{-19} C]

7. A rectangular coil of length 3 mm and breadth 2 mm possesses 200 turns. It is placed in uniform magnetic field of 0.03 Wb/m². Calculate torque acting on the coil when it is parallel to the field and perpendicular to the field, if current through the coil is 25 mA.

8. A rectangular coil of wire of 100 turns each of area 10 cm² hangs freely in a radial magnetic field of 200×10^{-4} Wb/m². When a current of 5 mA is passed through the coil, the coil is deflected through an angle of 60°. Find the torsional constant of the suspension fibre.

9. A cyclotron used to accelerate protons has a maximum radius of 0.4 m and B = 1 T. Find the frequency of oscillator used and the maximum velocity of cmerging protons.

Section B: Theoretical Board Questions

1. State the principle of movmg coil galvanometer. Show that the deflection produced in it is directly proportional to the current passing through it. **[Oct 96, Feb 01]**

2. Derive the necessary formula for shunt resistance required to convert M.C. galvanometer into ammeter. Explain why ammeter must have low resistance. **[Mar 97, 2000, Oct 06]**

3. Explain why
a. the resistance of ammeter should be low.
b. the resistance of voltmeter should be high. **[Oct 97]**

4. State the principle of moving coil galvanometer. Describe its construction with a neat diagram. **[Mar 99]**

5. What is the necessity of a radial magnetic field in the moving coil galvanometer? Explain how a moving coil galvanometer can be converted into an ammeter. **[Oct 2000]**

6. A galvanometer is shunted by $\frac{1}{r}$ of its resistance. Find the fraction of the total current passing through the galvanometer. **[Feb 01]**

7. State the principle of a moving coil galvanometer. Explain briefly how it can be converted into an ammeter. Derive the necessary formula. **[Feb 02]**
8. Explain how moving coil galvanometer can be converted into ammeter and voltmeter. Derive necessary formula. **[Feb 05, 06, Oct 06]**
9. State the principle of moving coil galvanometer and explain its working. **[Oct 08, Mar 11]**
10. Explain the principle of moving coil galvanometer (suspended coil type) **[Mar 10]**
11. Explain the construction and working of cyclotron. **[Oct 10]**
12. State the formula for sensitivity of moving coil galvanometer. How can its sensitivity be increased? **[Oct 10]**
13. State Ampere's circuital law and write its mathcmatical expression. **[Oct 11]**
14. State the principle of cyclotron. With a neat diagram explain its construction. **[Oct 11]**

Section C: Numerical Board Problems

1. A moving coil galvanometer of resistance 100 ohm gives a full scale deflection of 50 divisions for a current of 25 milliampere. How will you convert it into an ammeter to read 1 ampere for 10 divisions? **[Oct 97]**
2. A moving coil galvanometer of resistance 200 Ω gives full scale deflection of 100 divisions for a current of 50 mA. How will you convert it into an ammeter to read 2 A for 20 divisions? **[Oct 2000, 02]**
3. A galvanometer has a capacity to carry a maximum current of 25 mA. How can it be used as ammeter to read the current upto 0.1 A? **[Feb 03]**
4. Calculate the value of the shunt which when connected across a galvanometer of resistance 38 ohm will allow $\frac{1}{20}$ th of the current to pass through the galvanometer. **[Oct 05]**
5. A rectangular coil of effective area 0.05 m^2 is suspended freely in a radial field of 0.01 Wb/m^2. If the torsional constant of the suspension fibre is 5×10^{-9} Nm per degree, find the angle through which the coil rotates when a current of 300 μA is passed through it. **[Feb 06]**
6. A galvanometer has a resistance of 16 Ω. It shows full scale deflection when a current of 20 mA is passed through it. The only shunt resistance available is 0.06 Ω which is not appropriate to convert a galvanometer into an ammeter. How much resistance should be connected in series with the coil of galvanometer so that the range of ammeter is 8 A? **[Oct 13]**

Multipal Choice Questions

1. The magnetic field inside a long solenoid is
   a) non uniform b) zero
   c) uniform d) infinity
2. The strength of magnetic field along solenoid having 5000 turns per meter is 3.14×10^{-2} T. The current flowing through the solenoid is
   a) 2 A b) 3 A
   c) 4 A d) 5 A
3. Ampere's law is similar to
   a) Faraday's law
   b) Gauss' theorcm in electrostatics
   c) Joule's law
   d) Kirchhoff's law
4. If 'R' is the radius of dees and 'B' be the magnetic field of induction in which positive charge (q) of mass (m) escapes from the cyclotron, then its maximum speed (v_{max}) is ______
   a) $\frac{qR}{Bm}$ b) $\frac{qm}{BR}$
   c) $\frac{qBR}{m}$ d) $\frac{m}{qBR}$
5. Two parallel plates separated by distance dare kept at potential difference V volt. A charge q of mass m enters in parallel plates with some velocity. The acceleration of the charged particle will be ______
   a) $\frac{qV}{dm}$ b) $\frac{dm}{qV}$
   c) $\frac{qm}{dV}$ d) $\frac{dV}{qm}$

6. A solenoid of 1.5 m length and 4.0 cm in diameter possess 10 turns per metre. A current of 5 A is flowing through it. The magnetic induction at a point inside the solenoid along the axis is ($\mu_0 = 4\pi \times 10^{-7}$ Wb /Am)
a) $\pi \times 10^{-5}$ T b) $2\pi \times 10^{-5}$ T
c) $3\pi \times 10^{-5}$ T d) $4\pi \times 10^{-5}$ T

7. A long solenoid has a radius 'a' and number of turns per unit length is 'n'. If it carries a current 'i', then the magnetic field on its axis is directly proportional to
a) ani b) ni
c) ni/a d) n^2 i

8. In a current-carrying solenoid, the field produced does not depend upon
a) number of turns per unit length
b) current flowing through it
c) radius of the solenoid
d) all ofthese

9. An electron (mass = 9×10^{-31} kg, charge = 1.6×10^{-19} C) moving with a velocity of 106 m/s enters a magnetic field. If it describes a circle of radius 0.1 m, then strength of magnetic field must be
a) 4.5×10^{-5} T b) 1.4×10^{-5} T
c) 5.6×10^{-5} T d) 2.6×10^{-5} T

10. The torque acting on the coil is maximum if it is suspended in
a) uniform magnetic field
b) radial magnetic field
c) earth's magnetic field
d) earth's gravitational field

11. In a moving coil galvanometer, we use a radial magnetic field so that the galvanometer scale is
a) linear b) algebraic
c) logarithmic d) exponential

12. The coil of a sensitive M.C.G swings too far on both sides. This movcment can be quickly stopped by
a) holding a magnet near the coil.
b) earthing the case of the galvanometer.
c) connecting a large resistance across the ends of the coil.
d) connecting a short length of copper wire across the ends of the coil.

13. In radial magnetic field, the torque acting on the current-carrying freely suspended coil is
a) zero b) maximum
c) less than zero d) mmimum

14. In a moving coil galvanometer, for equilibrium of the coil,
a) deflecting torque is directly proportional to the square of restoring torque.
b) deflecting torque is equal to restoring torque.
c) deflecting torque is greater than the restoring torque.
d) deflecting torque is less than the restoring torque.

15. In M.C.G, 'K' is torsional constant of suspension wire and 'θ' is the deflection of coil. Then the restoring torque acting on the coil is
a) $K\theta$ b) $K^2\theta$
c) K/θ d) θ/K

16. The lamp and scale arrangcment is used for the measurcment of deflection in
a) suspended coil type M.C.G
b) pivoted coil type M.C.G
c) tangent galvanometer
d) potentiometer

17. In suspended coil type M.C.G, the coil is suspended in radial magnetic field by thin fibre of phosphor bronze because
a) it has high torsional constant.
b) it has low torsional constant.
c) it has negative torsional constant.
d) it has an adjustable torsional constant.

18. The deflection ill a M.C.G falls from 50 divisions to 10 divisions when a shunt of 12 Ω is applied. The resistance of the galvanometer coil is
a) 12 Ω b) 24 Ω
c) 48 Ω d) 50 Ω

19. The function of the shunt in ammeter is
a) to allow minimum current through the galvanometer.
b) to reduce the resistance of galvanometer.
c) both a) and b).
d) to increase resistance of galvanometer.

20. The range of ammeter can be increased by ____
a) decreasing series resistance
b) increasing series resistance
c) decreasing shunt resistance
d) Increasing shunt resistance

21. The M.C.G has resistance 'G' and 'I_g' be the minimum current for its full scale deflection. To convert M.C.G into ammeter of range I A, the required shunt is

a) $S = \left(\frac{I_g}{I - I_g}\right)G$ b) $S = \left(\frac{I_g - G}{I}\right)$

c) $S = \left(\frac{I_g}{G(I - I_g)}\right)$ d) $S = \left(\frac{I - I_g}{I_g}\right)G$

22. An ideal voltmeter has ______
a) low resistance b) high resistance
c) infinite resistance d) zero resistance

23. A voltmeter can be converted into ammeter by connecting
a) a low resistance in series
b) a low resistance in parallel
c) a high resistance in series
d) a high resistance in parallel

24. Which of the following has largest resistance?
a) Ammeter b) Milliammeter
c) Microammeter d) All of these

25. The resistance of an ammeter of 1 A range is $0.018\ \Omega$. How will you convert it to an ammeter measuring up to 10 ampere?
a) $0.2\ \Omega$ b) $0.02\ \Omega$
c) $0.002\ \Omega$ d) $0.001\ \Omega$

26. A potential difference of 0.75 V applied across a galvanometer causes a current of 15 mA to pass through it. If it can be converted into ammeter of range of 25 A, then required shunt should be
a) $0.3\ \Omega$ b) $0.03\ \Omega$
c) $0.003\ \Omega$ d) $0.0003\ \Omega$

27. The sensitivity of a galvanometer is 60 divisions/ampere. When a shunt is used, its sensitivity becomes 10 divisions/ampere. If galvanometer is of resistance $20\ \Omega$, the value of shunt used is
a) $4\,\Omega$ b) $5\,\Omega$
c) $20\ \Omega$ d) $8\,\Omega$

28. A galvanometer can be converted into a voltmeter by connecting a
a) high resistance in parallel
b) high resistance in series
c) low resistance in parallel
d) low resistance in series

29. The requircments of ideal voltmeter are
a) its resistance should be large
b) it should be direct reading type
c) it should be sensitive and accurate
d) all of these

30. A moving coil galvanometer gives full scale deflection when a current of 0.005 A is passed through its coil. It is converted into a voltmeter reading up to 5 V, by using an external resistance of $975\ \Omega$. The resistance of the galvanometer coil is
a) $25\ \Omega$ b) $30\ \Omega$
c) $40\ \Omega$ d) $50\ \Omega$

31. A voltmeter of resistance $2000\ \Omega$ reads 1 volt/division. The resistance required to be connected in series with voltmeter to make it to read 10 volt/division is
a) $18\ \Omega$ b) $180\,\Omega$
c) $1800\,\Omega$ d) $18000\,\Omega$

32. A voltmeter of resistance $1000\ \Omega$ reads 2 volt/division. The resistance required to be connected in series with voltmeter to make it to read 20 volt/division is
a) $18000\,\Omega$ b) $1800\,\Omega$
c) $9000\,\Omega$ d) $900\,\Omega$

33. The accuracy of M.C.G can be increased by
a) taking large deflection
b) decreasing number of turns
c) decreasing area of the coil
d) all of these

34. The S.I unit of current sensitivity is
a) ohm/div b) rad/A
c) amp/div d) volt/div

35. A rectangular coil of M.C.G of 100 turns of effective area 12 cm^2 hangs in a magnetic field of 1.5×10^{-2} T. If the torsional constant of the suspension fibre is 1.5×10^{-8} Nm per radian then current sensitivity of M.C.G. is
a) 0.12 radian/μA b) 12 radian/μA
c) 120 radian/A d) 0.24 radian/A

36. In a cyclotron, the resonance condition is that the frequency of the charged particle is equal to
a) the frequency of applied magnetic field.
b) the frequency of the applied a.c. voltage source.
c) frequency of the applied magnetic field and the frequency of the applied a.c. source.
d) none of these

37. A deuteron of kinetic energy 50 keV is describing a circular orbit of radius 0.5 m, in a plane perpendicular to .magnetic field $\vec{B}$. The kinetic energy of a 'proton that describes a circular orbit of radius 1.0 m in the same plane with the same magnetic field $\vec{B}$ is
a) 200 eV b) 50 eV
c) 100 eV d) 25 keY

38. A galvanometer of resistance $20\ \Omega$ gives a full scale deflection when a current of 0.04 A is passed through it. It is desired to convert it into an ammeter reading 20 A in full scale. The only shunt available is 0.05 Ω. The resistance that must be connected in series with the coil of the galvanometer is

a) 2.95 Ω b) 4.95 Ω

c) 4.35 Ω d) 4.25 Ω

39. A horizontal over head power line carries a current of 50 A in west to east direction. What is the magnitude of magnetic field, 1.5 m below the line?

a) 1.5×10^{-6} T b) 6.7×10^{-6} T

c) 7.7×10^{-6} T d) 8.7×10^{-6} T

40. Alternating current cannot be measured by D.C ammeter because

a) A.C cannot pass through D.C ammeter.

b) A.C changes direction.

c) average value of current for complete cycle is zero.

d) D.C ammeter will get damaged.

41. 50 turns of a wire of diameter 1 mm is wound on a cylinder of radius 5 cm. If the specific resistance of the material of the Wire is $4.5 \times 10^{-6}\ \Omega$ m, then its resistance is

a) 9 kΩ b) 900 Ω

c) 250 Ω d) 90 Ω

42. A galvanometer having a resistance 'G' and a current 'I_g' produces a full scale deflection. 'S_1' is the value of shunt which converts it into an ammeter at range 0–1 and 'S_2' is the value of shunt for the range 0–2I. The ratio S_1/S_2 is

a) $\frac{1}{2}\frac{(I-I_g)}{(2I_g-I_g)}$ b) $\frac{2I-I_g}{I-I_g}$

c) 1 d) 2

43. Two circular coils are made of two identical wires of same length. If the number of turns of the coil are 4 and 2, then the ratio of magnetic induction at centres will be

a) $\frac{4}{1}$ b) $\frac{1}{4}$

c) $\frac{1}{2}$ d) $\frac{2}{1}$

44. A moving coil galvanometer of resistance 'G' gives full scale deflection for certain current. The shunt resistance required to convert it to measure a current 'n' times of initial current is ______

a) (n – I)G b) $\frac{G}{(n-1)}$

c) $\frac{(n-1)}{G}$ d) nG

45. The resistance of galvanometer is G. If S is the resistance used to convert the galvanometer into an ammeter, then the effective resistance of the ammeter is

a) G + S b) G – S

c) $\frac{G+S}{G\cdot S}$ d) $\frac{G\cdot S}{G+S}$

46. An ammeter is obtained by shunting a 30 ohm galvanometer with a 30 ohm resistance. What additional shunt should be connected across it to double the range?

a) 15 Ω b) 10 Ω

c) 5 Ω d) 30 Ω

47. The area of a rectangular coil is 0.04 m². It is suspended freely in a radial magnetic field of induction 0.04 Wb/m². The torsional constant of the suspension fibre is 2×10^{-9} Nm per degree. A current of 40 microampere is passed through the coil, determine angle of rotation of the coil.

a) 16° b) 32°

c) 48° d) 64°

48. Maximum current and voltage range of a galvanometer are 25 mA and 500 mY. What modifications are to be incorporated in the instrument to measure currents upto 25 A in the second case to measure voltage upto 250 volt?

a) Shunt resistance = 0.08 Ω, series resistance = 6880 Ω

b) Shunt resistance = 0.06 Ω, series resistance = 7880 Ω

c) Shunt resistance = 0.04 Ω, series resistance = 8880 Ω

d) Shunt resistance = 0.02 Ω, series resistance = 9980 Ω

49. The resistance of a voltmeter is 50 ohm. Find the reading of the voltmeter when it is connected in series with a cell of e.m.f 1.5 V and internal resistance of 10 Ω.

a) 4.25 V b) 3.25 V

c) 2.25 V d) 1.25 V

50. The magnetic field at the centre of the current carrying coil

a) is directed normal to the plane of coil.
b) is directed parallel to the plane of the coil.
c) is zero.
d) has none of the above characteristics.

51. A galvanometer may be converted into ammeter or a voltmeter. In which of the following cases, the resistance of the device so obtained will be the largest?
a) Ammeter of range 1 A
b) Ammeter of range lOA
c) Voltmeter of range 1 V
d) Voltmeter of range 10 V

52. If 10% of the main current is to be passed through the moving coil galvanometer of resistance 99 ohm, then the required shunt resistance will be
a) 9.9 Ω b) 10 Ω
c) 11 Ω d) 9 Ω

53. A voltmeter of range 5 V is to be converted into an ammeter of range 10 mA. If the resistance of voltmeter is 1 kΩ, then what resistance should be connected in parallel with it?
a) 0.2 kΩ b) 0.5 kΩ
c) 0.8 kΩ d) 1.0 kΩ

54. A long wire carries a steady current. It is bent into a circle of one turn and the magnetic field at the centre of the coil is 'B'. It is then bent into a circular loop of 'n' turns. The magnetic field at the centre of the coil will be
a) n B b) n^2B
c) 2nB d) $2n^2B$

55. If in a moving coil galvanometer a current 'I' produces a deflection 'θ', then
a) $i \propto \tan\theta$ b) $i \propto \theta^2$
c) $i \propto \theta$ d) $i \propto \sqrt{\theta}$

Answer Keys

1. c)	2. d)	3. b)	4. c)	5. a)	6. b)	7. b)	8. c)	9. c)	10. b)
11. a)	12. d)	13. b)	14. b)	15. a)	16. a)	17. b)	18. c)	19. c)	20. d)
21. a)	22. c)	23. b)	24. c)	25. c)	26. b)	27. a)	28. b)	29. d)	30. a)
31. d)	32. c)	33. d)	34. b)	35. a)	36. b)	37. c)	38. b)	39. b)	40. c)
41. d)	42. b)	43. a)	44. b)	45. d)	46. b)	47. b)	48. d)	49. d)	50. a)
51. d)	52. c)	53. d)	54. b)	55. c)					

Answers :

Section A

1. 5×10^6 degree/ A
2. $9 \times 10^{-3}\,\Omega$
3. 26.32 Ω
4. 2400 Ω
5. $2\pi \times 10^{-3}$ T
6. 1.554 T
7. 9×10^{-7} Nm, Zero
8. 9.55×10^{-6} Nm/rad
9. 15.26 MHz, 3.8×10^7 m/s

Section C

1. 0.503 Ω should be connected in parallel with the galvanometer.
2. A shunt of resistance 1.005 Ω should be connected in parallel with galvanometer.
3. Connecting a shunt of resistance G/3 ohm in parallel with the galvanometer.
4. 2 Ω
5. 30°
6. 7.94 Ω